AC 2008-2393: THE IMPACT ON ENGINEERING GRADUATE STUDENTS OF TEACHING IN K-12 ENGINEERING PROGRAMS

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The Impact on Engineering Graduate Students of Teaching in K-12 Engineering Programs

Many K-12 engineering education initiatives implemented by U.S. universities and colleges have been well documented, providing us with descriptions of program logistics, partnerships, methods and curricula, as well as the impact on involved students, teachers and undergraduate and graduate students.[1-9] Several initiatives have further evaluated their participating engineering students and revealed measurable impacts in the areas of communication, teamwork, understanding of K-12 education, and time management.[1-6]As one of those established K-12 engineering programs, we are specifically interested in addressing the question, "How have engineering students' experiences with K-12 engineering education affected the students' capabilities and long-term impacts on the K-12 community?"

Many of our nation's K-12 engineering programs were initiated through support from the National Science Foundation's GK-12 program, whose programmatic purpose is to address national issues in K-12 education by using science, technology, engineering and math (STEM) graduate students as resources for K-12 teachers and schools.[10] The GK-12 program seeks to disseminate models of excellence that include opportunities for K-12 teachers, students, and STEM undergraduate and graduate students.[10] The long-term impacts of these programs are important to judging their overall successes, as well as validating program continuations. As individual initiatives mature and researchers reflect upon their university/school district models and accomplishments, analyses of long-term program effects are expected to surface in the literature.

The TEAMS (**T**omorrow's **E**ngineers… cre**A**te. i**M**agine. **S**ucceed.) Program^2 is one such K-12 engineering initiative that has been underway for nine years — long enough to permit analysis of significant patterns of impact on graduate student participants. Evaluation of the TEAMS Program includes the effects of the K-12 engineering program on graduate student development (their evolving attitudes and skills), as well as the long-term residual impact on students' post-graduation involvement in K-12 engineering. Our TEAMS program appraisal includes quantitative data on engineering graduate student Fellows' skills, attitudes and impacts gathered through surveys, in-classroom teacher feedback and K-12 engineering staff observations. This paper provides a summary of our assessment approaches, results and lessons learned, as well as successful strategies to develop skills some engineering graduate students find difficult.

What is TEAMS?

The University of Colorado at Boulder's award-winning Integrated Teaching and Learning (ITL) Program conducts a grades 3-12 engineering initiative to promote science, math, engineering and technological literacy and increase the number of high school graduates prepared for — and interested in — choosing an engineering future. One component of the ITL's K-12 initiative is engaging undergraduate and graduate engineering students to teach in K-12 science, math and technology classes and serve as engineering role models in six local schools.

Partially funded by National Science Foundation GK-12 and U.S. Department of Education FIPSE grants, the ITL's TEAMS Program targets the high diversity and low academic performance student populations of the Lafayette, Colorado, schools. Partnering with the teachers and administrators of a continuum of six schools (four elementary and one middle school that feed into a high school with a four-year pre-engineering program), a cadre of university students teach engineering curricula to more than 1,600 youngsters weekly in 58

grades 3-12 classrooms to make hands-on engineering exploration part of every child's educational experience. Engineering graduate and undergraduate TEAMS Fellows serve as engineering role models in K-12 science, math and technology classes through teaching STEM subjects within a hands-on engineering context.

The Graduate Fellow's Role

Working alongside partner teachers, TEAMS Fellows bridge engineering subject area content to age-appropriate education pedagogy through hands-on engineering activities specifically mapped to K-12 content standards. In addition to classroom teaching, graduate TEAMS Fellows develop and classroom test original engineering lesson plans to support their classroom interactions and for eventual online publication and dissemination.

A K-12 engineering Fellow "in action" at a Colorado elementary school.

During 2007-2008, the graduate TEAMS Fellows at CU-Boulder impacted students *weekly* in 58 classrooms in four elementary schools (827 students), one middle school (600 students), and one high school (210 students). The Fellows' STEM expertise and engaging hands-on activities have become an integral teaching component for partner teachers and a highlight for the students.

Who are the Fellows?

Since 1999, 68 Fellows have taught in the TEAMS Program. Currently, in the ninth year of this intensive in-class, academic year engineering initiative, these engineering graduate students — whose own lives have been impacted by TEAMS — have influenced the lives of thousands of youth in Lafayette-area schools. Of our 68 TEAMS Fellows, 49% have been female, 6% Latino and 3% African American — in fact, over-representing the diversity in our engineering college.

The 2007-2008 cohort of TEAMS graduate fellows.

While most of our college's engineering disciplines have been represented by our TEAMS Fellows over the years, the Program seems to especially attract students from CU-Boulder's Department of Civil, Environmental and Architectural Engineering — popular among Fellows for its *Engineering for Developing Communities* program, which appeals to students who are motivated to give back to their community. In the nine years of the program, students matriculated from (or are currently enrolled in) the following engineering departments: civil/environmental/architectural, 57%; mechanical, 19%, aerospace, 15%; electrical, 4%; chemical/biological, 4%; and applied math, 1%.

With regard to Fellow retention in the program, we encourage (in alignment with NSF GK-12 program guidelines) Fellows to remain in the Program for two academic years, although early graduations and other situations do arise. Over the nine years, of the 41 Fellows eligible to

reapply to renew their TEAMS Fellowship for a second year, 24 did reapply — 12 females and 12 males. Of those who reapplied, only two Fellows were not eligible for reappointment due to their poor academic performance; the remaining 22 graduate Fellows accepted our offers to serve a second year in the Program. And much to our delight, about half of our Fellows stay engaged after the school year to assist with our intense summer K-12 engineering workshops.

Program Goals

The overarching goals of the TEAMS Program include enhancing the capabilities and impacts of the engineering graduate student Fellows throughout their K-12 exposure and beyond. The Program's specific objectives include preparing Fellows for effective classroom content delivery, improving their communication skills, and strengthening their STEM knowledge. By engaging Fellows during their graduate studies and providing them a significant K-12 teaching experience, we hope to inspire in them a lifelong passion for K-12 engineering involvement, perhaps as a teacher or member of the engineering/technology workforce. Over the years, we have evaluated Fellows' skills and attitudes through numerous assessments of the Program's participating students, K-12 teachers and principals, TEAMS staff, and graduate Fellows themselves.

Program Assessment

The TEAMS Program is assessment driven. Throughout the year, an emphasis is placed on a continuous evaluation cycle, with quantitative and qualitative methods used to assess the TEAMS Program's success in meeting its objectives. We have developed assessment criteria for each TEAMS Program objective, and carefully selected assessment methods to measure each criterion; an outside evaluation of our assessment techniques and results is done yearly.

To gain a broader view of Fellow performance in the classroom, assessment methods were triangulated with ratings of Fellow performance in the classroom taken from four different sources: a mid-year classroom teacher survey, TEAMS Program staff observations of Fellows teaching, a Fellows focus group conducted mid-year, and Fellows' self-ratings taken at the end of the year. In addition, TEAMS Program alumni Fellows were surveyed to determine the longer-term program impact. Quantitative survey questions were rated on a five point Likert-type scale, with five equal to a high rating. Qualitative survey and focus group data consisted of responses to open-ended questions. See the appendix for example assessment tools.

TEAMS Program assessment data were collected from the inception in fall 1999 through fall 2007, with new assessment tools phased in as the initiative evolved. K-12 mid-year teacher surveys have been collected since the first year, with 213 teacher ratings collected overall. Fellow self-ratings have been collected since the second year, with feedback provided from 52 Fellows. Focus group data have been collected since the fifth year of the program, with feedback from 35 Fellows. In the last three years, 24 staff observations have also been collected. Formal and informal communication has been collected from alumni Fellows, with 27 responding to the most current survey on the long-term impact of their K-12 teaching experience.

Assessment Results

Quantitative assessment results from teachers, staff and Fellows are presented in Table 1. Fellow teaching skills and impact categories are listed in descending order according to the magnitude of the overall average rating. The top ranked skill categories are similar to those reported in the literature by other K-12 engineering programs.[1,3-6]

Table 1: Summary of 68 Fellows' Skill and Impact Ratings over Nine Years

Skills and Impact Categories	Fellows' Self-Ratings	Teacher Ratings	Program Staff Ratings	Overall Average
Fellow served as an engineering role model	4.56	4.71	4.85	4.71
Communication skills	4.58	4.47	4.68	4.58
Working well with K-12 teachers	4.33	4.70	4.69	4.57
Fellow STEM content knowledge	4.38	4.63	4.71	4.57
Working well with students of all ethnicities and genders	3.81	4.78	4.94	4.51
Ability to integrate engineering curriculum into the classroom	3.80	4.03	3.77	3.87
Classroom management skills	3.34	3.64	4.39	3.79
Rating scale: 1 (lowest) to 5 (highest)				

Throughout the nine years of the TEAMS Program, ratings of Fellow teaching effectiveness are generally ranked "good," 4 out of 5 points. The Fellows' excellent communication skills and their abilities to serve as engineering role models generally receive the highest ratings, 4.5 out of 5 points for these categories. These ratings are supported by qualitative data; for example, K-12 teachers viewed "enthusiastic engineers demonstrating their passion and knowledge of engineering" as an enhancement to the classroom. One teacher commented, "A well-prepared personable instructor who can relate to students and communicate classroom expectations makes the TEAMS Program work in my classroom." Staff observations also highlighted Fellows' communication skills, with one staff pointing out that the Fellow did a "good job at knowing names," and a "great job of engaging girls." Finally, Fellows themselves report an increase in their communication skills. For example, one former Fellow reported, "I can speak in front of large groups more confidently after my tenure as a Fellow!"

Two skill categories were consistently rated the lowest across the duration of the program — especially by Fellows themselves. While the first category, "integrating engineering curriculum into the classroom," still received a "good" rating by teachers, both staff and teacher observations corroborated that Fellows were challenged in this area and that disruption of the day-to-day classroom curriculum flow sometimes became an issue.

- "Remember to place the activity in an engineering context by letting the students know which types of engineers use this knowledge." *(Staff observation)*
- "There are times when I begin a [non-engineering] lesson the day before my TEAMS Fellow arrives that does not quite get finished; I then have to postpone that lesson and make room for the TEAMS lesson." *(Teacher survey)*

Another difficult skill category for Fellows is the development of effective classroom management techniques. Classroom management skills consistently received the lowest ratings

from Fellows, teachers, and program staff, with all noting concerns and offering suggestions for improvement in this challenging skill area.

- "Keeping the focus of the third-graders… it is a lot of work to keep them occupied. They drift real easily. Fourth and fifth graders are more 'trained' to pay attention or return to attention. Classroom management for the young ones is difficult." *(Fellow focus group)*
- "Students are very skilled at taking advantage of other people who aren't their regular classroom teachers. So, sometimes the classroom management piece can be a challenge, especially with activities that are very interactive." *(Teacher survey)*
- "Work on not allowing just a few students to control the discussion." *(Staff observation)*

With regard to the development of a lifelong passion for K-12 engagement, results from the Fellow alumni survey are encouraging. Of the 27 alumni Fellows who responded, 93% reported that they are still interested in K-12 engineering, with more than half (55%) having already participated post-graduation. Most of their work has been in a volunteer capacity; for example, judging science fairs, guest lecturing about engineering in K-12 classes, and mentoring design competitions. However, a portion of Fellows (15%) indicate that K-12 engineering is part of their professional responsibilities. One alumnus Fellow who completed her doctorate is now a mechanical engineering instructor at CU-Boulder and is involved in grant-sponsored research into the reasons high school girls go on to choose a career in engineering. Another former Fellow started a company which offers the opportunity for high school students to become involved in building elementary schools in developing communities. Yet another Fellow alumnus is teaching aerospace engineering at a high school as part of Project Lead the Way. Last, but not least, a past Fellow is coordinating the current incarnation of the TEAMS program and co-authoring this paper. Even years later, some of our former Fellows harbor big dreams, envisioning for their own future some deeper involvement in K-12 engineering activities such as developing a program for minority students in math, science and engineering; working with inner city schools that are academically struggling; and aligning themselves with the K-12 academic programs that their company offers. We intend to follow and report on their progress.

Turning to the long-term impacts of participating in the Fellows program, our alumni primarily target the development of a lasting appreciation for teaching and the impact of teaching experience on the development of their pedagogical and communication skills. Many of the respondents reported increased respect for the difficult job of teaching in K-12 schools. One noted, "I realized teachers did not get enough credit for the job that they do." Others were inspired by the experience to become teachers themselves, "My time as a Fellow confirmed that I love education. Teaching and mentoring is really important to me, and I want to help young people understand how they can change and improve their world." This former Fellow is initiating a hands-on K-12 engineering program in his company — demonstrating that his K-12 teaching experience had a lasting effect. Another former Fellow reported, "that program is the reason why I am now an assistant professor… After completing the GK-12 program in 2002-2003, I knew I wanted to pursue my PhD, so that I could follow my two passions: teaching and structural engineering." Fellow alumni also point out the long-term impact on their teaching and communications skills after participating in the program. One Fellow, now a university instructor, commented that her experience has greatly enhanced her pedagogical skills: "One of the greatest benefits of participating in the K-12 outreach initiative was that it made me a more engaging and creative lecturer/instructor/professor." Another stated, "Developing curriculum for

children was excellent practice in taking challenging concepts and explaining them in easy-to-understand ways. This skill came in handy when I worked for a forensic biomechanics firm, and we had to present our expert testimony to juries who had no understanding of physics or biomechanics."

Lessons Learned and Suggested Strategies

As we reflect on our TEAMS Program with regard to graduate student engagement in the art of teaching K-12 engineering, we realize that our own focus on Fellow development has matured over time, and that we have learned many lessons. While we continue to employ the processes that allow us to grow Fellows' communication skills and select and train the type of Fellows who are excellent engineering role models, we have modified our program to better address the integration of engineering curriculum in the classroom and to shore up Fellows' classroom management skills.

We have found that Fellows are challenged to effectively integrate engineering — with a focus on engineering design — into their classroom. Too often they expend so much effort delivering the science concepts to youngsters at the age-appropriate level, that they inadequately incorporate the exciting, real-world engineering connections that make the concepts relevant. To help with this, we now require Fellows to plan their activities at least one week in advance and communicate with K-12 staff and partner teachers on their intended activity, its engineering connection and associated math skills. With this approach, Fellows benefit from an array of valuable suggestions before teaching the lesson in the classroom.

We now also understand the importance of infusing the graduate Fellows into the culture of their school by scheduling them to teach at fewer schools for longer periods of time each year (i.e., we generally assign one Fellow to only one school). This cultivates deeper relationships and better integration between the K-12 students and teachers, and their graduate engineering student Fellows. And, Principals and teachers view them as "their Fellow."

As an outgrowth of this one-on-one school partnership, we have learned the importance of providing quality and continuity in curricular resources for Fellows' use. To meet this need, we require each Fellow to document weekly classroom reports and lesson plan summaries that are saved for future Fellows' reference. These documents are useful to new Fellows when meeting with their teachers in advance of the school year. With this historical information, Fellows are equipped to inquire about which lessons worked well and which did not, so as to build on past experiences in planning their role in the upcoming year.

In addition to the weekly lesson plan summaries, we have found it important to provide Fellows with high-quality instructional curricula. Throughout the year, Fellows use the already-developed *TeachEngineering* curricula for their classroom instruction. This online *TeachEngineering*[11] digital library (http://www.teachengineering.org), part of the National Science Digital Library, is a collection of engaging hands-on engineering curricula on topics mapped to K-12 state science and math standards. The collection serves as a nationwide resource for K-12 engineering curricula and is available free to educators. Fellows publish their own original classroom-tested activities; their use of and contribution to this resource helps refine and grow its contents.

We have learned that time management is a huge contributor to the successful integration of Fellows in the classroom. Good K-12 teaching is extremely time-consuming, so we help our Fellows find a balance between K-12 teaching and their graduate studies, developing an

individualized classroom plan for each Fellow. Even a well-prepared Fellow may experience difficulty in over-planning activities for the classroom.

Classroom management skills are another aspect of teaching that requires time to develop. Fellows begin their classroom management training the summer *before* their academic year assignment by learning basic strategies for working with K-12 students. Through shadowing veteran Fellows, weekly classroom management seminars and teacher mentoring — as well as immersion in summer K-12 engineering workshops — new Fellows begin to hone their own skills and build their confidence. Fellows meet with their teachers in August to plan the upcoming semester; then they spend the first week or two in their new classroom observing students and the teacher, learning student names and generally becoming comfortable with the environment. Classroom management and pedagogy are reinforced throughout the TEAMS experience via mandatory weekly Fellows seminars on topics such as teaching tools, social styles, assessment strategies, time management, techniques for grouping students and sharing of stories from the classroom.

Lastly, we have found it beneficial to foster a setting in which the TEAMS Fellows can become a close-knit group — spending time together in weekly seminars, university classes and events outside of the TEAMS Program. This camaraderie is evident when veteran Fellows mentor new Fellows, setting the tone for the upcoming year (i.e., teamwork begins early!). We nurture these relationships by providing a dedicated space for our Fellows to work together and in dedicating time for the Fellows to share their own successful — and challenging — stories during the weekly seminar. Their winning attitudes and sense of belonging to something larger than themselves carry over into the classrooms.

Conclusion

Many K-12 engineering programs have reported measurable impacts on graduate Fellows involved in K-12 engineering education in the areas of communication, teamwork, understanding of K-12 education, and even time management.[2-6] During the nine-year tenure of ITL's TEAMS Program we have examined the effects of our K-12 engineering teaching experience on graduate students' attitudes and skills development, and refined assessment measures, researched significant impacts during and after the Program, and made programmatic changes based on our findings.

With a TEAMS Fellow, youngsters explore the physics of sound through a hands-on engineering activity.

In summary, our Fellows received solid marks on many of the TEAMS program skills objectives, including the necessary STEM content knowledge, communication skills, and the ability to "work and play well" with teachers and other students. Classroom management and the art of integrating engineering into the traditional science classroom continue to be the most challenging skill performance areas for our graduate engineering student Fellows. Our continual implementation of new approaches has helped grow Fellows' confidence in these skills. With many of the honed K-12 teaching skills, such as confidence in

classroom and group communication, some of our graduated Fellows have found these skills parlayed into their professional lives.

Across the board, we have seen a lasting impact of the Program in our Fellows' post-graduation interest and involvement in K-12 engineering initiatives. All of our former Fellows still regard their K-12 teaching experience as influential in some way, evidenced by the many who have engaged in short-term and volunteer K-12 engineering community opportunities. In this way, and in their future intentions, the passion for K-12 engineering that was instilled or supported by the TEAMS Program early on continues post-college.

The TEAMS Program's infusion of 60+ new engineering graduates enthused about K-12 engineering into the working world opens up myriad possibilities. It would be advantageous for companies to leverage the passion of these budding engineers by providing and supporting industry-based opportunities to increase the technological literacy of K-12 youth through hands-on engineering experiences — fostering the engagement of their engineering employees as ambassadors of our profession. We are hopeful that as the graduate Fellows who have been involved in K-12 engineering programs throughout the nation become leaders in their companies, this will naturally occur.

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Appendix: Assessment Tools

TEAMS Program Fellows Teaching Evaluation

Date_____

Fellow_____

Evaluator_____

Please circle the response that you agree with using the scale below.

SD = Strongly Disagree; D = Disagree; N = Neutral; A = Agree; SA = Strongly Agree

1. Activity is well researched and understood	SD D N A SA
2. Activity is captivating for youth	SD D N A SA
3. Supporting materials are well prepared	SD D N A SA
4. Activity is taught within an engineering context	SD D N A SA
5. Connections of the activity to the real-world are made	SD D N A SA
6. Concepts are taught at the appropriate grade level	SD D N A SA
7. All students in the class are engaged or encouraged to engage	SD D N A SA
8. Activity is taught with enthusiasm	SD D N A SA
9. Fellow responds appropriately to spontaneous questions	SD D N A SA
10. Effective classroom management techniques are employed	SD D N A SA
11. Displayed effective verbal communication skills	SD D N A SA
12. Worked well with the classroom teacher	SD D N A SA
13. Was an effective engineering role model for the students	SD D N A SA
14. Was knowledgeable about science, technology, engineering, and math content	SD D N A SA
15. Worked well with students of all ethnicities and gender.	SD D N A SA

Other feedback/suggestions:

TEAMS Teacher Feedback Survey

The purposes of this survey are to help us continuously improve the TEAMS Program and meet National Science Foundation grant requirements. Your feedback is greatly appreciated.

1. What do you like best about the TEAMS Program?

2. Are you looking forward to participating in the TEAMS Program in your classroom next school year? ❒ Yes ❒ No

   Please elaborate:

3. As an outcome of the TEAMS initiative, how much more knowledgeable are you about engineering as a career? (Please circle a number)

Significantly		Somewhat		Little to None
5	4	3	2	1

   Comments?

4. Has participation in the TEAMS Program had an effect on your skill and comfort with inquiry-based, hands-on teaching methods? ❒ Yes ❒ No

   Please elaborate:

5. How well does the K-12 engineering curricula provided by the Fellow(s) support science and/or math content standards for your grade level?

Significantly		Somewhat		Little to None
5	4	3	2	1

   Comments?

The following items relate to your experience with your Fellow(s); please circle your response for each.

SD=strongly disagree; D=disagree; N=neutral; A=agree; SA=strongly agree

My Fellow(s)…

a.	delivered effective K-12 engineering curriculum for my students.	SD	D	N	A	SA
b.	verbally communicated effectively with me.	SD	D	N	A	SA
c.	was an effective verbal communicator with my students.	SD	D	N	A	SA
d.	was able to work well with me as the classroom teacher.	SD	D	N	A	SA
e.	was an effective engineering role model for my students.	SD	D	N	A	SA

f.	knowledgeable about science, technology, engineering, and math content.	SD	D	N	A	SA
g.	experienced difficulty integrating engineering curriculum into the classroom.	SD	D	N	A	SA
h.	worked well with students of all ethnicities.	SD	D	N	A	SA
i.	worked well with students of both genders.	SD	D	N	A	SA
j.	experienced disciplinary problems with my students.	SD	D	N	A	SA
k.	wrote effective weekly lesson plans.	SD	D	N	A	SA
l.	was an asset to my classroom and to student learning.	SD	D	N	A	SA

6. How do you perceive that the attitude of your students towards engineering — such as becoming more comfortable with the concept of engineering or imagining themselves as engineers — has evolved as an outcome of their involvement in the TEAMS Program?

7. Overall, what do you most dislike about the TEAMS Program? Please elaborate — we value your constructive criticism!

8. How would you suggest we modify the TEAMS Program to better suit your needs?

9. In addition to engineering curriculum brought to your classroom by Fellows(s), have you directly used curriculum from the TeachEngineering digital library? ❒ Yes ❒ No

   If yes, how would you characterize your experience?

Please provide additional comments — we value your input!